Study of Shipboard Power Distribution System: Review on an Aplication of AC Zonal Distribution

Danang Cahyagi[1], Eddy S. Koenhardono[1]

***Abstract*—The shipboard power distribution system has been developed in order to make it more efficient. AC zonal distribution system is one of the options in order to achieve the objection. This study aims to observe the shipboard application with AC zonal distribution system. The distribution system is modeled, simulated, analyzed, and compared with conventional system. Based on simulation, the AC zonal distribution system provide higher reliability, better power continuity, and more stable power generation. Therefore, development of the zonal distribution system continues to bring succeed in every mission. However, the system has several challenges for future work such as more complex transmission system, higher voltage drops, and the tendency to have instability power distribution when one generator fails.**

***Keywords*— Shipboard Power System, AC Zonal Distribution, Load Flow Analysis, Transmission System.**

INTRODUCTION

In shipboard power system, the continuity of the electrical operation could affect the quality of services [1]. Failure of an electrical component has a variety of other consequences [2]. For example, the electrical distribution failure may cause an interuption of movement, machinery, or cargo services. In addition, failure of the electrical system also gives an impact to the crew and the mission carried. Therefore, the development of electrical distribution system is one objection to improve ship's power distribution quality [1], [3], [4].

Failure of the electrical distribution system can be caused by internal factors such as damage of transformers, circuit breakers, busses, and cables. The external factors such as bad weather, physical accident, and human error also could affect shipboard power distribution [5].

In general, segregated distribution has become widely used as shipboard power system. Segregated power distribution is a system that separates between the main propulsion system and the auxiliary system [6]. This system has advantages in terms of installation, maintenance, and operation. However, the system has several disadvantages such as unusable excess power when the propulsion system in verry low speed or non-moving. The failure of main power plant or main transmission line may cause blackout or even deadship condition [7], [8].

One of the shipboard power distribution development is the zonal distribution system [4], [9], [10].

Zonal distribution systems offer more efficient power usage, and better power continuity. Zonal distribution can be performing with ac or dc system [6].

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This study aims to provide a comparison between AC zonal distribution system and segregated distribution system.

LITERATUR REVIEW

Shipboard power system is divided into mechanical propulsion systems and electric propulsion systems [11]. Mechanical propulsion with diesel direct has advantages such as low capex, and low complexity. While the electric propulsion with diesel electric has advantages such as flexible layout, and manouverability. Both of systems also have diadvanatges. The disadvantages of diesel direct system are dirty, noisy, and inflexible in the ship layout. The disadvantages of diesel electric is less efficient than diesel direct at cruising speed [12].

Mechanical propulsion system consists of main power system and auxiliary system. The main system in the mechanical propulsion is a power generation with diesel, natural gas, or nuclear as propulsion plant. The power is used for driving propeller to provide ship's thrust. The auxiliary system in the mechanical propulsion system serves as a power generation to supply the electrical equipment that used to support the main engine system, or the other loads [13], [14].

Electric propulsion system is a method that change the propulsion system from the mechanical drive into the electric motor. The electric motor supplied by generator as main power plant. The electric propulsion plant can be installed with independen or parallel with auxiliary system [11].

There are several electrical distribution systems. They are segregated systems, radial systems, and zonal distribution systems [6]. Each electrical distribution systems have pros and cons. Generally, the system selection is based on ship operation modes, services, and rules.

The literature study of conventional system and modern system is described as follows.

A. Conventional System

Segregated and radial distribution system has been widely used as ship power distribution system [6]. Conventional ac ship power systems are based on the radial power distribution and having separate generators for propulsion and service loads.

In a segregated distribution system (see Figure 1), the power to operate the main propulsion system is installed independently with the auxiliary system. Usually, the ships are driven by diesel engines, steam turbines, gas turbines, and nuclear as mechanical driver. The auxiliary system is used to support the main machinery systems such as fuel, lubrication, and engine cooling systems. The auxiliary system also provides the power for loading and unloading, deck machinery, HVAC, electronic control systems, communications equipment, workshop, and accommodation [15].

In a radial system (see Figure 2), the main propulsion and auxiliary system are integrated. The radial distribution system consists of feeders, and branches. Feeder is the main circuit of power plant system, and the branch circuit separates the supplied power to the amount of loads. Radial system may consist of one or more branches. The branch can be one phase, or three phase. In radial system, main propulsion and electrical equipment have one or two transmission line from feeder. With this characteristic, a radial distribution system also known with integrated power system [5].

The development of a radial distribution system with an electric propulsion provides higher efficiency in term of design and operation. The advantages of radial system are related to failure spot determination, voltage regulation, and load flow preditiction. However, the radial system also has a disadvantage such as equipment dependency on one or two distribution lines. If there is feeder or main transmission damage, the electrical equipment below will also fail [5], [16].

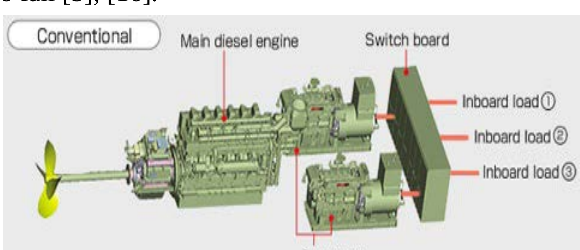

Figure 1. Typical segregated power distribution system [17].

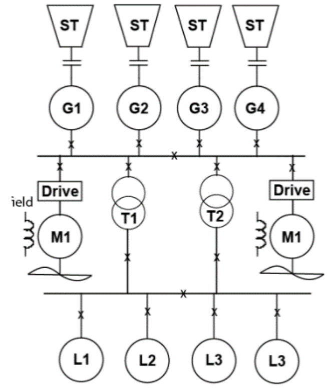

Figure 2. Typical radial distribution system [6].

B. Modern System

When radial distribution system has been widely applied, the need for more efficient distribution systems recently gained priority. The system is expected to have higher survivability, reliability and efficiency. The zonal electrical distribution (ZED) is emerging as one of the most suitable candidate power system architecture to achieve these objective [6].

In contrast with radial systems, the zonal distribution system could achieve higher survivability by separating the distribution system into zones and maintaining independent power sources in each zone [9]. Zonal distribution system is divided into AC zonal distribution, and DC zonal distribution [6]. One of the shipboard aplication of zonal is warships power distribution [4].

According to Dubey and Santoso [1], the zonal distribution system is considered as a method for obtaining a reliable distribution system. In their research, DC zonal distribution system is designed with new circuit, equipment placement modification, and topology optimalization. In conclusion, the distribution system can be optimized with all of these methods. The most optimal system is the breaker and a half topology (BAAH) system.

AC zonal distribution has been installed on USS Arleign Burke (DDG-51), and USS Makin Island [14], [18]. The AC zonal distribution is able to be configured as a ring bus and utilizes a radial distribution methodology from the load centers [18]. The difference between the zonal distribution system with other vessel systems is the ability to distribute power with two rails ie the portside bus rail, and the starboard bus rail (see Figure 3). Bus rail and ship electrical loads are geographically integrated into individual zones with co-located load centers. This distribution system has longer cables with higher current carrying capacity.

Based on literature review, the AC zonal distribution is able to accommodate a more reliable distribution system. Power distribution on electrical load can be supplied with more than one network. Thus, the system still survive even there is one line failure.

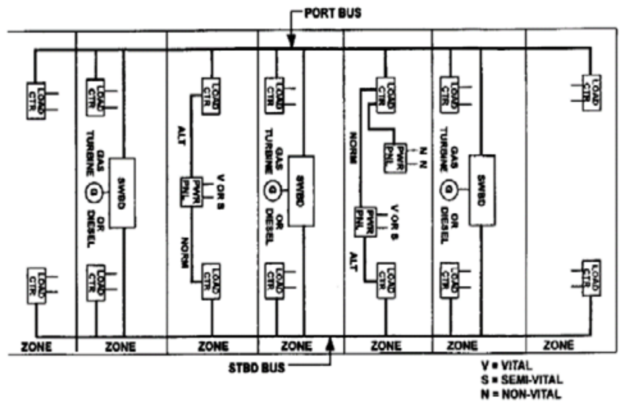

Figure 3. USS Arleign Burke AC ZEDs power distribution system [18].

EXPERIMENTAL

In this study, we give comparisson of shipboard power distribution system between conventional and zonal distribution. The specifications of power generation systems, propulsion loads, and service loads in one typical ships are shown in Table 1.

TABLE 1.
SHIP'S POWER PARAMETER IN ONE TYPICAL CONVENTIONAL DISTRIBUTION

Ship's Power Parameter	Value
Propulsion Power Plant (kW)	3,100
Propulsion Motor (hp)	3500
Generator (kW)	3 x 700
Load 1 (kVA)	200
Load 2 (kVA)	200
Load 3 (kVA)	400
Load 4 (kVA)	400

To determine the system performance, the power distribution is designed, and simulated with the computer software. The research objection in this study are load flow, distribution simulation at the failure condition, and power plant usage. The power distribution on the vessel is designed with two topologies. The first design is a conventional distribution system, and the second design is zonal distribution system. In this study, we used AC zonal distribution system.

A. Conventional Power Distribution System Design

The study of conventional power distribution system is conducted with modeling electric propulsion – segregated power distribution (see Figure 4). The power generation system between the main propulsion machinery, and auxiliary load is independently designed. Each power generation system may not affect to each other.

The power generation system for main propulsion machinery is supplied with 3100kW generator. The propulsion driver is a 3500hp synchronous motor. The system designed at 20kV. There are several devices that connect between the propulsion plant and motor such as bus, breaker, and transmission cable.

Power generation systems for auxiliary load are supplied with three generator units 700kW at 20kV. Three generator units are parallely operated. Electrical equipment are loads with low voltage 400V. Therefore, the distribution system is equipped with a step down transformer. The distribution system has been branched with the bus to four service loads

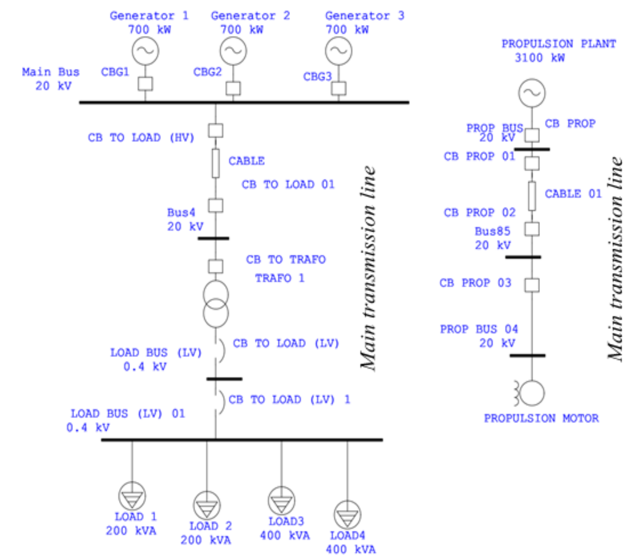

Figure 4. Modelled power distribution with conventional method

B. AC zonal distribution system design

The performance of AC zonal distribution system is conducted with combining propulsion machinery and other electrical loads (see Figure 5). The system is designed by reconfiguring the generator capacity, and electrical places. The total power generated is remains the same with the convention system. The distribution system reconfiguration parameters with AC zonal distribution are shown in Table 2.

TABLE 2.
SHIP'S POWER PARAMETER FOR AC ZONAL DISTRIBUTION SYSTEM

Ship's Power Parameter	Value
Generator (kW)	4 x 1300
Load 1 (kVA)	400
Load 2 (kVA)	200
Load 3 (kVA)	200
Load 4 (kVA)	400

The AC zonal distribution have four generators 1300 kW. The generation system operate at 20kV. There are eight high-voltage buses that provide the power for all loads. Four electrical loads divided into four zones. Each load can be supplied from two different buses.

The step down transformer installed at each load zone. The transformer serves to reduce the 20kV voltage from buses to load nominal voltage 400V.

The placing of 200kVA and 400kVA loads also changed. The 200kVA loads are placed as Load 2 and Load 3. While the 400kVA loads are placed as Load 1 and Load 4.

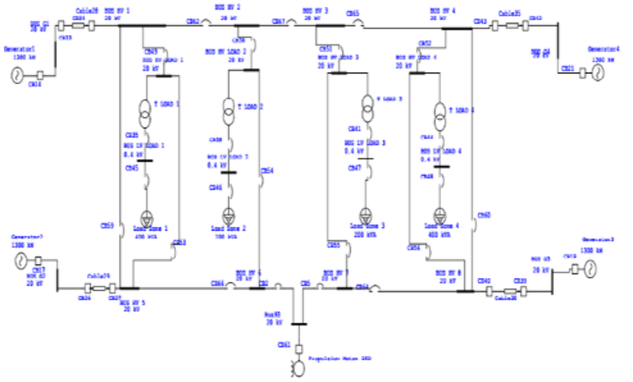

Figure 5. Modelled power distribution with AC zonal distribution sytem

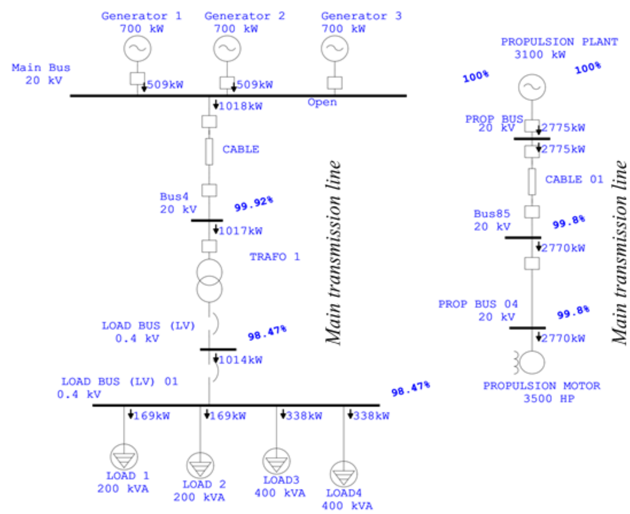

Figure 6. Power simulation result with conventional method

RESULT AND DISCUSSION

A. Conventional distribution system analysis

Conventional power system consists of two independent systems. They are main propulsion, and auxiliary system. In main propulsion system, the power supplied to operate a 3500hp motor is 2770kW. The recorded voltage on the motor bus is 19.96kV or 0.2% decreases from voltage source (see Figure 6).

The auxiliary distribution is arranged with radial system. Two of the three generators are parallely operated. The generators operate at 509kW of maximum capacity 700kW. The total power of both generators are 1018kW. The power is branched to four loads. In Load 1 and Load 2, the power supplied at 169 kW. In Load 3 and Load 4, the power supplied at 338 kW. Voltage on the load branch bus recorded at 393.9 V or 1.53% decreases. The drop voltage may caused by characteristic, and transmission system length.

One auxiliary generator is in standby condition. The purpose is to achieve power continuity when another generator damage or in repair condition. The unusable generator is disconected from the auxiliary bus feeder. Then the standby generator is operated on the same line.

Based on simulation, the radial system has several disadvantages. The failure of propulsion power plant, or main transmission line may cause the propulsion motor is out of service. Although the system has a 700 kW standby generator, the generator can not be used because of different transmission systems. Main transmission line could become source of hazzard. Since transmission system arranged in series, failure on one transmission component such as transformer, circuit breaker, bus, and transmission cable may cause entire system down.

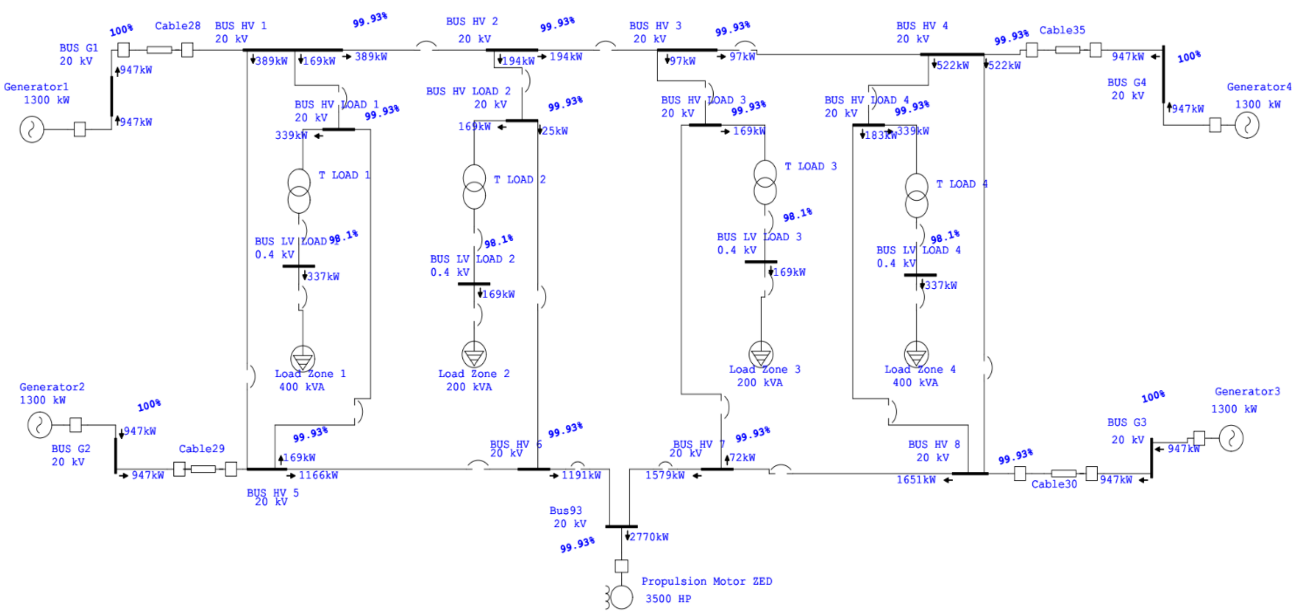

Figure 7. Load flow simulation result with conventional power distribution system

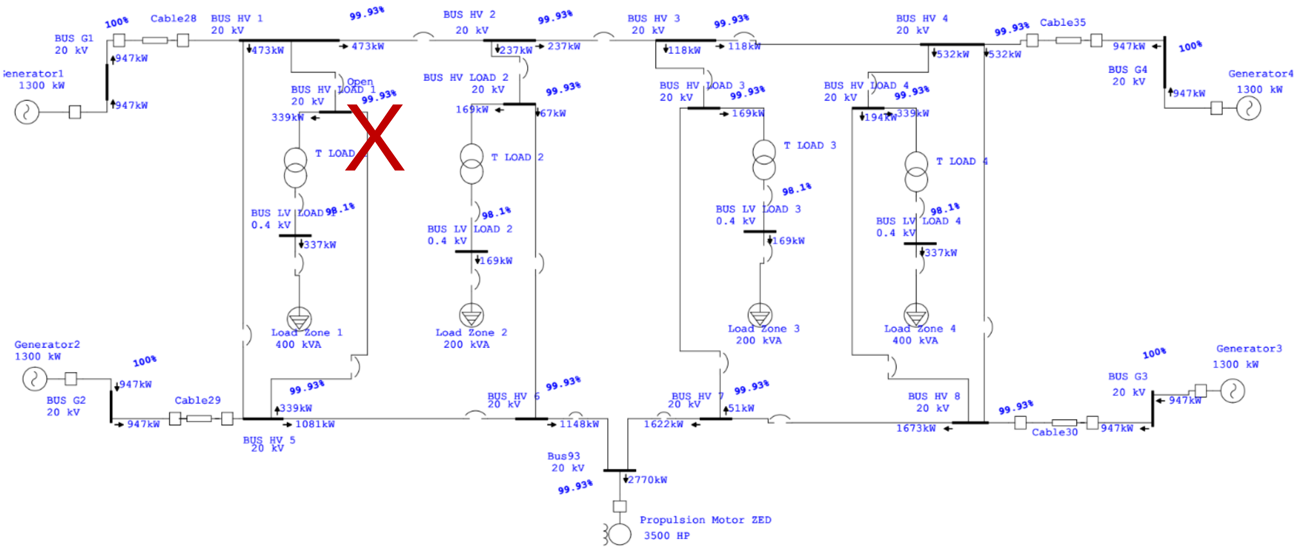

Figure 8. Simulation result with one load zone line failed (Load Zone 1)

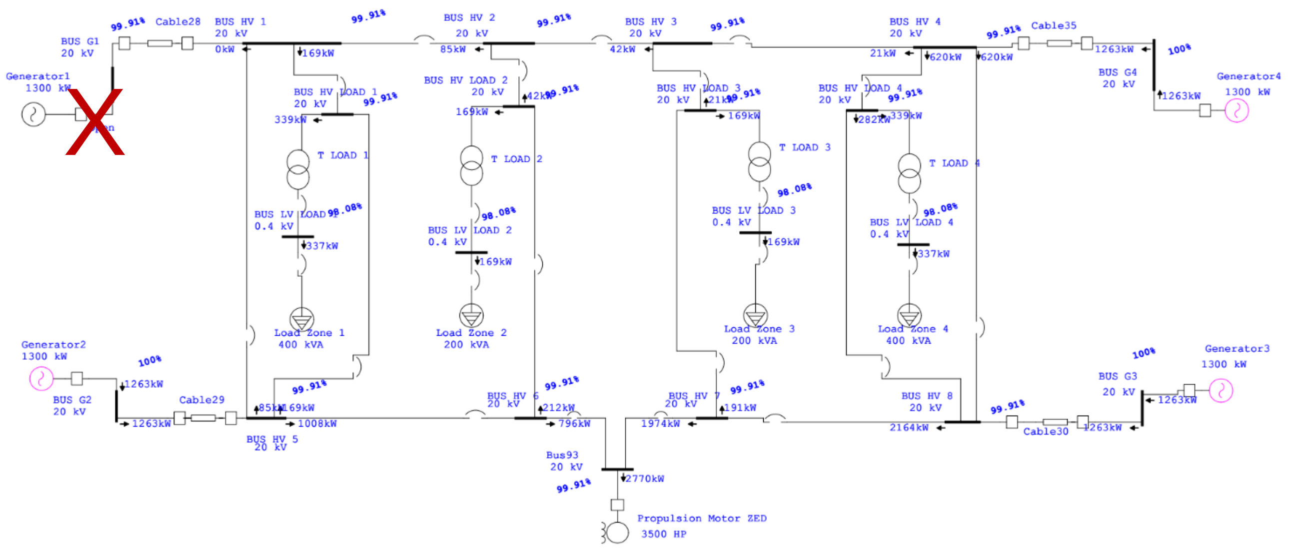

Figure 9. Simulation result with one generator fail (Generator 1)

B. AC zonal distribution system analysis

In AC zonal distribution, power generation for main propulsion, and auxiliary system are integrated designed (see Figure 7). To activate propulsion motors and auxiliary loads, four generators operate at 947 kW of 1300kW maximum power. The power supplied to the propulsion motor is 2770kW or equal to the power of the conventional system. The voltage read on the propulsion motor bus is 19.98kV or 0,07% decreases from voltage source. The voltage drop is lower then conventional system (0,2%).

Load 2 and Load 3 operate at 169kW. While Load 1 and Load 4 operate at 337kW. The voltage in Load 1 - 4 is 392 V or decrease 1.9% from the source.

Based on the simulation results, propulsion motors and Load Zone 1-4 are supplied with the following scenario,

1. Load Zone 1 is supplied from Bus HV 1 and Bus HV 5. Bus HV 1 and Bus HV 5 provide 169kW power supply. Power received at Bus HV Load 1 are 339kW.
2. Load Zone 2 is supplied from Bus HV 2. The Bus HV 2 delivers power at 194kW. Bus Load 2 receives power at 169kW. 25kW power is forwarded to Bus HV 6.
3. Load Zone 3 is supplied from Bus HV 3 and Bus HV 6. Bus HV 3 and Bus HV 6 provide 97kW and 72kW respectively. Bus HV Load 3 receives power at 169kW.
4. Load Zone 4 is supplied from Bus HV 6. Bus HV 6 provides 620kW of power. The Bus HV Load 4 received 339kW. 282kW Power is forwarded to Bus HV 8.
5. 3500hp propulsion motor is supplied trough Bus HV 6 and Bus HV 7 at 1191kW, and 1579kW respectively. Accepted power at motor bus are 2770kW.

AC zonal distribution system offers higher reliability. Since the load can be supplied by more than one lines. When one line fails, the load will be supplied through another line. Figure 8 shows the failure simulation on one line to Load Zone 1. When the line from the Bus HV 1 fails, power is supplied from the Bus HV 5. Under normal circumstances, Bus HV 1 and Bus HV 5 supply power at

169kW. But when the supply from Bus HV 1 fails, the Bus HV 5 provides a power supply at 339kW.

Figure 9 shows failure simulation on Generator 1. When Generator 1 fails, the power supply from another generator increase to accommodate all loads. In normal condition, Generator 1 - 4 provides power at 947 kW. When Generator 1 fails, Generator 2 - 4 will operate at 1263kW. However, the power generated by generator 2 – 4 almost reaches the maximum operating limit. So it is recommended to add power capacity at design stage to accommodate failure of one generator.

C. AC zonal distribution advantages

With AC zonal distribution, the electrical load can be distributed by more than one lines. Failure on one line will be covered by another lines. So the electrical load can still operate.

The AC zonal distribution system is also capable to provide the power even one of the generators fails. When one generator down, the propulsion motor still operate under normal condition as well as the auxiliary system.

When the conventional system works at maximum conditions, the propulsion generator operate at 89%, while the auxiliary generator operates at 72.5% of maximum rate. With AC zonal distribution, all generators work at 72.8% of maximum rate. It is mean the AC zonal distribution system has more stable generator output power generation.

D. AC zonal distribution disadvantages

Although AC zonal distribution offers higher reliability, this system has several disadvantages.

AC zonal distribution requires a higher current carrying capacity for transmission system. Based on generator failure simulation (see Figure 9), the Bus HV 8 supplies the highest power at 2167kW or 68 amps at a voltage of 19.98kV. When in normal conditions, Bus HV 8 only supplies 1651kW or 51.9 amps of power at the same voltage.

Since the AC zonal distribution system has a more complex transmission system, drop voltage Load 1 - 4 on the AC zonal distribution system is higher than the radial system. In the radial system, the voltage drop occurred at 1,53%. While the voltage drop on the AC zonal distribution system occurred at 1,9%.

CONCLUSION

The development of shipboard AC zonal distribution continues to achieve more efficient power distribution system. This objection is belongs to maritime stakeholder, especially who put system reliability into highest priority in order to bring succeed in every mission. Based on simulation, AC zonal distribution offers higher reliability, better continuity, and more stable power generation as the advantages. The AC zonal distribution also has several challenges for future work such as more complex transmission system, higher voltage drop, and the tendency to have instability power distribution when one of the generators fails.

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